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OBSERVATIONS ON THE BEHAVIOR OF WHITE SHARKS SCAVENGING FROM A WHALE CARCASS AT POINT REYES, CALIFORNIA

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ABSTRACT

Scavenging of marine mammal carcasses is thought to be an important part of the diet of white sharks (*Carcharodon carcharias*), though scientific observations of this behavior are rare. A detailed analysis of this feeding behavior has not been previously reported, nor has it been compared with

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the documented predatory feeding habits of this species. On 9 October 2000 we observed and photographed three white sharks scavenging on the carcass of a humpback whale (*Megaptera novaeangliae*) near Point Reyes, California. The sharks most often fed individually; however, simultaneous feeding by two white sharks was observed. The sharks targeted the outer blubber layer of the carcass, avoiding previously exposed muscle tissue. Ocular rotation and palatoquadrate protrusion, behaviors commonly associated with white shark predations, were not observed. The significance of these behaviors are discussed and contrasted with the reported predatory feeding behaviors of this species.

INTRODUCTION

The ecology and behavior of white sharks, *Carcharodon carcharias*, in eastern Pacific waters have been described in numerous articles, usually with focus on their occurrence at pinniped colonies (e.g., Ainley et al. 1985, Klimley et al. 2001) or descriptions of attacks on humans (e.g., McCosker and Lea 1996). Comparatively few articles have been published on the trophic relations between white sharks and cetaceans, and those that exist are primarily descriptions of shark-bitten cetaceans that occasionally wash ashore (Long and Jones 1996). Behavioral observations of scavenging sharks are scarce in the literature. The paucity of data is due to the unpredictability of these events and the rarity of having trained scientists present.

In the northeastern Pacific, juvenile white sharks feed on a variety of demersal bony fishes and elasmobranchs (Klimley 1985). As these sharks grow and mature their diet shifts to marine mammals, notably northern elephant seals, *Mirounga angustirostris*, and California sea lions, *Zalophus californianus* (Klimley 1985). These pinnipeds have an insulating fatty tissue layer, and it is postulated that this tissue provides the white shark with the energy necessary to meet the metabolic demands of maintaining elevated body temperatures, acquiring large size, and active foraging in cool waters (Tricas and McCosker 1984, Goldman 1997). Though white sharks will actively pursue seals, sea lions (Ainley et al. 1981, 1985), and odontocete whales (Long and Jones 1996, Heithaus 2001), they have not been reported to prey upon living mysticete whales, but will opportunistically scavenge their carcasses (see Table 1). It has been suggested that this scavenging activity comprises a major portion of the adult white shark's diet in certain parts of its range such as the northwest Atlantic (Carey et al. 1982), or during certain times of the year when pinniped prey are not readily available (Long and Jones 1996).

Most of the existing information regarding white shark behavior while scavenging on whale carcasses consists of anecdotal accounts from fishermen (Randall 1973, Ellis 1975). Only Pratt et al. (1982) and Dudley et al. (2000) reported some detailed behavioral descriptions of shark scavenging events. Here we present new first-hand observations of three white sharks scavenging on a whale carcass. The significance of these behaviors are discussed and contrasted with the reported predatory feeding behaviors of this species.

Table 1. Documented accounts of white sharks scavenging on whales. Species of whale and number of white sharks present are indicated if reported by the original author.

Date	Location	Whale species	Sharks	Source
1896	Mediterranean Sea, near Italy	blue or fin whale	"many"	Parona 1896 ^a
Nov 1910	Mediterranean Sea, near Italy	fin or minke whale	?	Damiani 1911 ^a
Jul 1960	Block Island, Rhode Island	blue whale	12-15	Ellis 1975 (p. 90)
May 1972	western Australia	unknown	?	Randall 1973
Jun 1979	Moriches, New York	fin whale	4-9	Pratt et al. 1982
1982	central California	gray whale	1	McCosker 1985
Aug 1988	San Francisco, California	blue whale	5	Long and Jones 1996
Aug 1993	Durban, South Africa	humpback whale	?	Dudley et al. 2000
Apr 1998	Durban, South Africa	Bryde's whale	3-4	Dudley et al. 2000

^ain Bianucci et al. 2000

Scientific name key: blue whale, *Balaenoptera musculus*; Bryde's whale, *B. edeni*; minke whale, *B. acutorostrata*; fin whale, *B. physalus*; gray whale, *Eschrichtius robustus*

MATERIALS AND METHODS

On 2 October 2000 a dead humpback whale, *Megaptera novaeangliae*, drifted into Drake's Bay (38°00'00"N, 122°58'12"W), located in Marin County, California. The bay is a part of Point Reyes National Seashore (PRNS) which is within the Gulf of the Farallones National Marine Sanctuary. The cause of death of the 7.6-m immature male (REJ, Field No.1681) could not be determined. The carcass, whose ventral surface floated 1 m above the waterline, appeared to be relatively fresh and was estimated to have been adrift for no more than 2 or 3 days as judged by the presence of live external parasites, skin condition, and the low level of tissue decay. When initially observed, the carcass was already accompanied by a number of feeding white sharks, which were observed from the nearby bluffs. The sharks followed the carcass until it washed onto a rocky reef in < 2 m depth, at which point they appeared to depart the immediate area.

The beached whale carcass was closely inspected by THC, RKL, REJ, the California Marine Mammal Stranding Network response team, and several staff of PRNS. Photographs were taken of shark bites along the whale's left side (Fig. 1). These

photographs, each containing a reference object for scale, were digitized and upper jaw perimeter of the biting sharks were calculated from the images.

The carcass remained ashore or adrift in shallow water until 9 October when three of the authors (THC, KLM, and RKL) returned to PRNS to launch our research skiff at the site. Just prior to our launch at 1330 hours, the carcass slipped free of the reef and began to drift seaward with the ebbing tide. We took the opportunity to approach the carcass, which was now in an advanced state of decay, for further inspection as it began to drift offshore for the first time in over a week.

White sharks appeared between 1430 to 1445 hours, approximately 1 h after the carcass drifted out of the shallows and had been carried over a depth of 6-7 m. Shark total lengths (TL) were estimated by comparisons to the length of the carcass and to markings on the side of our boat. Presence or absence of claspers was noted. Observations of shark behavior and photographs were taken over the next 3 hours while the whale drifted offshore. The sharks fed in numerous active feeding bouts during this time. Observations were curtailed at 17:30 hrs because of approaching nightfall.

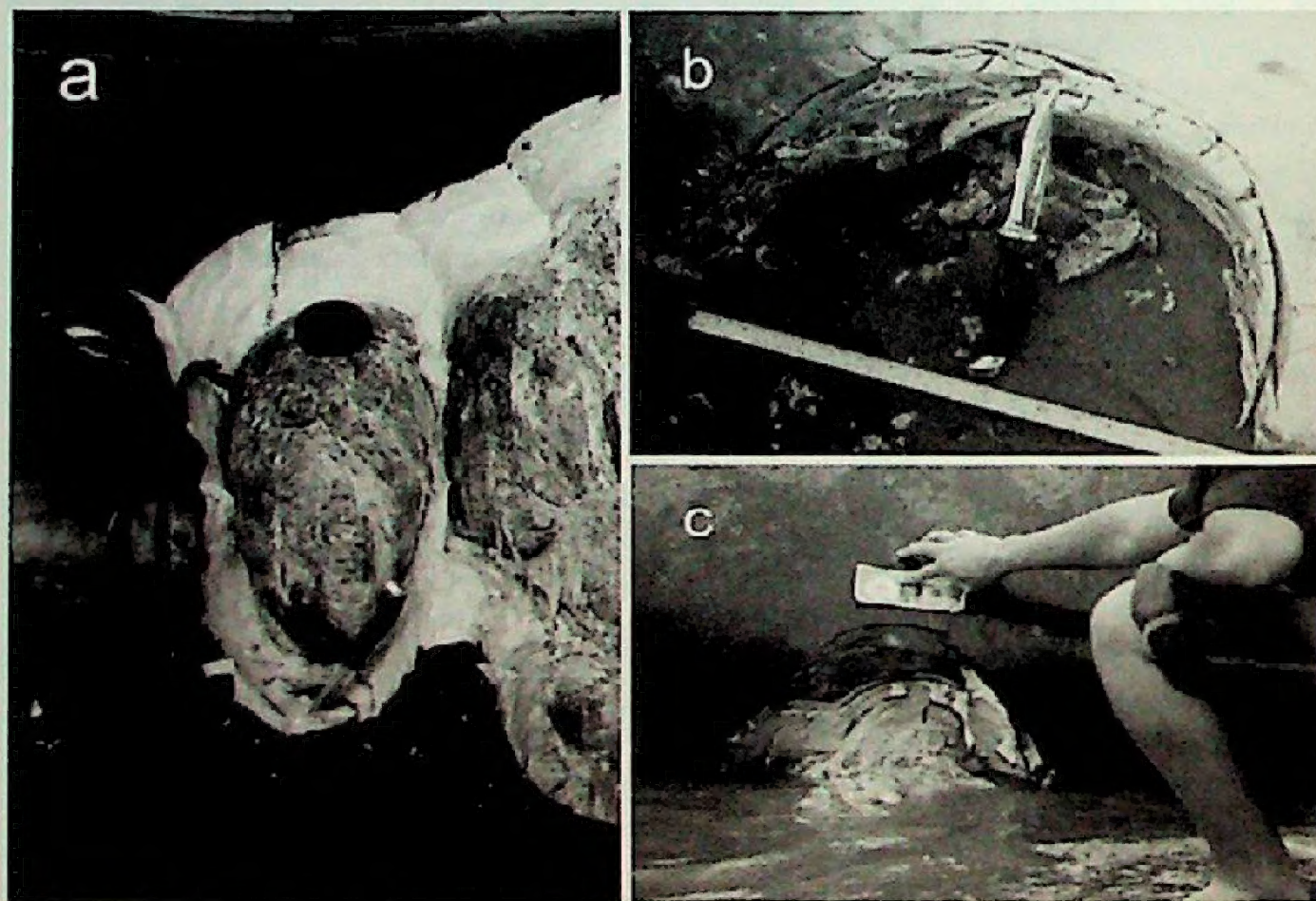


Figure 1. Examples of white shark bite marks on the carcass of a recently deceased humpback whale which washed ashore 2 October 2000 in Drake's Bay, California: a) multiple bites along the midsection of the whale. Note that blubber constitutes the bulk of the removed tissue; b) two superimposed bites from one of the flippers; c) multiple bites from the whale's midsection. Objects included for scale: knife (25.7 cm), US one dollar bill (15.6 cm) (photographs: a and b by R. Jones, c by T. Curtis).

RESULTS

The lengths of the sharks that scavenged from the carcass prior to its beaching in Drake's Bay were calculated based on measurements of bite perimeter (Fig. 1) and regressions of upper jaw perimeter versus TL (Mollett et al. 1996). The sharks that created these bites were estimated conservatively between 2.8 and 4.2 m in length. It should be noted that bites such as these can appear larger, smaller, or distorted due to a number of factors (Long and Jones 1996); however, the sharks we witnessed feeding on the carcass from shore on 2 October were estimated to be within this range.

Three white sharks, distinguished from one another by unique scarring patterns on their dorsal surface and fins, were determined to be present during the observation period on 9 October. The first shark to appear at approximately 1430 hours (WS1) was a male estimated to be 4.5 m TL. He was easily distinguished from the other sharks by a massive wound on his left dorsum just posterior to the first dorsal fin, including a large semicircular cut out of the dorsal fin itself. These wounds were relatively fresh and suggested a recent collision with the propeller and lower unit of a boat engine.

WS1 individually fed on the carcass for 15 minutes until two other white sharks (WS2 and WS3) arrived within 5 minutes of each other at about 1445 hours. Both sharks were approximately 3.5 m TL. WS2 was female, but the sex of WS3 could not be determined. WS1 moved away from the carcass at this time, and WS2 and WS3 began to feed. Typically, the sharks fed individually; however, on two occasions, we observed WS2 and WS3 simultaneously actively feeding on the carcass, with one shark on either side of the whale. We witnessed the vigorous head shaking of WS2 at one side of the carcass somewhat anterior of the midsection, and a moment later WS3 surfaced on the opposite side and began biting into the whale's posterior midsection. The force exerted by the two sharks as they fed steadily spun the carcass on the surface in a counterclockwise manner. This episode of simultaneous feeding lasted 1-2 minutes until WS2 moved off with a mouthful of tissue. Simultaneous feeding by multiple white sharks has never been reported in the literature to date.

It was not always possible to determine which shark was feeding on the carcass, so we were unable to quantify how much time each shark fed relative to the others, or estimate each individual's total food intake. However it appeared that through the remainder of the observations both WS2 and WS3 fed more often than WS1. During the few times WS1 was observed to feed again, WS2 and WS3 were not observed at the carcass. During these times, these individuals separately approached our boat, circling closely for periods of 1-5 minutes each time.

Feeding bouts by individual sharks ranged from <1 minute up to 10 minutes. We defined a feeding bout as the presence of a shark at the surface near the carcass and consisting of at least one attempt to remove flesh. This could comprise of a single bite, but more often several bites were attempted per bout. Between bites within a bout, the sharks typically circled the carcass at the surface before feeding from a new location on the whale. These bouts were regularly followed by prolonged periods of absence of up to 35 minutes before another feeding bout commenced. Except for the occasions when WS2 and WS3 were observed feeding simultaneously, only a single shark would

feed while the other two sharks generally remained below the surface and out of sight.

A typical feeding bout began with a period of investigative circling at, or just below, the surface, after which the shark would approach to within one body length of the carcass, before aligning its body perpendicularly to the whale. The shark typically impacted the carcass after 1-2 sweeps of its caudal fin, similar to the "surface charge" described by Tricas and McCosker (1984) and Tricas (1985). Just prior to impact, the shark would raise the anterior portion of its body, open its mouth, and use its forward momentum to drive into the carcass at an elevated angle. During this propelled surface bite, we did not witness palatoquadrate (upper jaw) protrusion, and only in one instance did we witness protective eye-rolling behavior. Once the upper and lower teeth were anchored in the carcass, the shark would begin a series of lateral head shaking movements, moving as far as 20° to the left or right of its vertical axis (based on photographic analysis, e.g., Fig. 2), removing a section of tissue in the process. Often during this head shaking, the shark's body would sink to a more vertical position. Additionally, at times the sharks would also roll onto their side while biting. We did not observe these sharks feeding fully inverted, as Pratt et al. (1982) described in their observations.

The sharks did not appear to feed on the carcass below the surface of the water, although we cannot be certain due to poor water visibility. They focused their feeding at the waterline, along the softer midsection of the whale, between the flippers and the caudal peduncle. The sharks were observed to scrape the blubber from the carcass with their teeth in a type of "raking" action. Though most of the flesh removal was from the midsection, large bites were also taken out of the whale's flippers and the fluke (Fig. 1b). The sharks were occasionally observed biting parts of the head, but little flesh was removed except for some sites along the mouth. At times the sharks would bite into these tougher parts of the whale's body, and then release their grip and shift position.

There appeared to be a clear preference for the outer blubber layer of the whale (Fig. 1a and Fig. 3). Even with the advanced state of decay of the carcass, the sharks did not appear deterred from feeding on the blubber. Sharks were not often observed returning to feed on parts of the carcass where the blubber had already been removed and the underlying muscle tissue exposed (Fig. 1a). The sharks swam at relatively slow speeds, and were deliberate in their movements. The swiftest movements of the sharks occurred during the propelled surface bite.

DISCUSSION

Descriptions of white shark predator-prey interactions dominate the literature associated with this large marine predator. There are several existing descriptions of the various behavioral and physiological components associated with its predatory feeding behavior (e.g. Tricas and McCosker 1984, Powlik 1995). There has been no analysis to date of the scavenging feeding behavior of white sharks, even though authors such as Carey et al. (1982) postulated that whale carcasses provide a large portion of the white shark's food needs. While it is not possible to make a definitive analysis of this subject based solely on the observations of three individuals, our

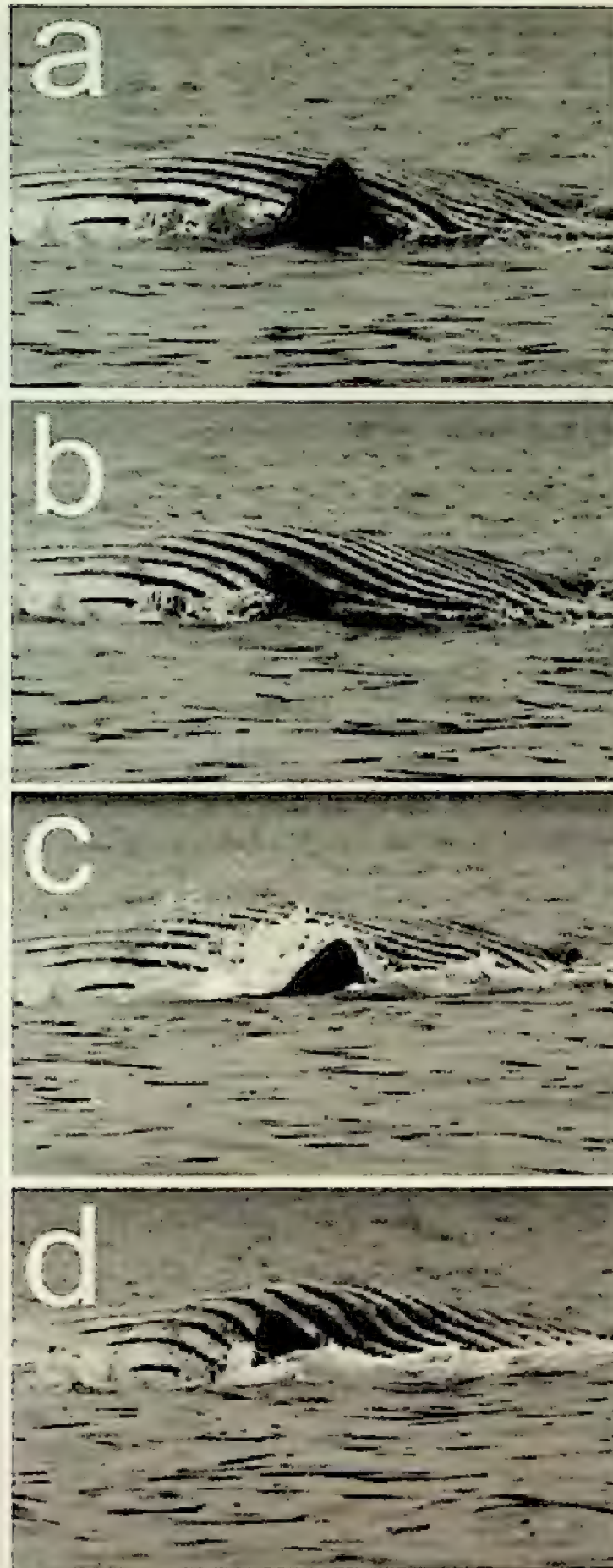


Figure 2. Time-series of the lateral head shaking behavior employed by white sharks scavenging from a whale carcass. The sequential photographs were taken at approximately 1 second intervals. This behavior is believed to enhance the cutting action of the teeth so that large pieces of flesh can be efficiently removed (photographs by K. Menard, 9 October 2000).



Figure 3. White shark in the act of scavenging from the whale carcass which is floating ventral side up in Drake's Bay, CA, 9 October 2000. Note how the sharks have preferentially removed the outer blubber layer along the midline of the carcass between the flipper and the caudal peduncle, leaving the muscle tissue below largely untouched. Similar tissue removal can also be made out along the right side of the carcass (photograph by T. Curtis).

observations indicate some ways in which the white shark's scavenging behavior may differ from its predatory habits.

Given the high energetic value yet stochastic availability of large carcasses, it is reasonable to expect that as many sharks as possible will attempt to exploit the resource. Indeed, reports of white shark scavenging events typically describe the presence of several sharks (Table 1). At a scavenging occurrence in July 2000, near a seal colony off South Africa, at least 28 individual white sharks were identified over an 18-hour period (C. Fallows and A. Kock, South African Museum, personal communication), though other accounts more typically describe 1-9 sharks.

The volume of fluids leaching from such a large decaying animal clearly has the potential to draw sharks from great distances depending on environmental factors affecting the distribution of the odor corridor. The oil slick emanating from this carcass was observed on the water's surface up to several kilometers away, and could have attracted sharks from at least that distance. The three sharks we observed on 9 October may or may not have been the same individuals that initially fed on the carcass before it washed ashore on 2 October. However, the near instantaneous arrival of these three sharks once the carcass returned to deeper water suggests that they had been loitering nearby, attracted by the scent of the whale. This is not unexpected as the Point Reyes area is a known white shark aggregation site (Kelly and Klimley 2003) due to the

seasonal abundance of elephant seals. Once the carcass was pulled offshore, the sharks were present and ready to take advantage of the abundant food source.

Congregations such as these may be a relatively infrequent event in the life of the white shark, and clearly creates the potential for a variety of social interactions not normally witnessed in this mostly solitary species. In particular, one might expect agonistic displays like those described by Klimley et al. (1996a) and Pratt et al. (1982) as the sharks compete for the food resource. Interestingly, distinct social interactions were not observed in these three sharks. Some forms of subtle visual communication may have occurred, but poor water clarity limited any subsurface observations.

While there are no previous records in the scientific literature of multiple white sharks feeding simultaneously from the same carcass as we report here, due to the sheer size of a whale carcass, the resource is neither limiting nor necessarily defensible for a single individual. This contrasts with predation on smaller prey species such as pinnipeds where there appears to be either hierarchal order, or direct competition, for resources manifested in agonistic displays (Klimley et al. 1996a). In the scavenging scenario, competitive, possibly injurious, interactions may be unlikely to occur as there is no advantage to be gained from guarding the resource. It is possible that the paucity of reports of this activity stem not from the rarity of the behavior, but rather the chance nature of the observation. The majority of whale carcasses and carcass scavenging occur offshore, out of sight of humans, and also possibly below the surface since not all whale carcasses float.

The synchronous arrival at the carcass by WS2 and WS3, and their simultaneous feeding bouts, are also notable observations and could indicate some degree of association between these individuals. In previous reports (e.g., Pratt et al. 1982), white sharks appeared to exclude both conspecifics as well as sharks of other species from feeding. In these cases, only one individual was observed to feed at any given time. In an observation similar to that which we report, though, Dudley et al. (2000) observed tiger sharks, *Galeocerdo cuvier*, concurrently scavenging a whale carcass with white sharks. He hypothesized that the observed competitive displacement of a single 400-cm white shark was due to the presence of several smaller (350 cm) tiger sharks. The tiger sharks showed no intraspecific aggression even though up to five individuals fed concurrently.

If white sharks do tolerate the presence of similarly sized conspecifics and maintain some sort of loose affiliation, it might permit smaller animals to displace larger animals and gain access to an important food resource to each individual's benefit. WS1 did not feed when WS2 and WS3 were present, and was possibly displaced even though he was a larger individual. Alternately, this could also have been due to the injured, potentially weakened state of WS1.

Our observations of scavenging bite behavior differ from the white shark's documented predatory behavior in two aspects: absence of protective ocular rotation and absence of palatoquadrate protrusion. Since white sharks lack a nictitating membrane for protection of the eyes, tailward rotation of the eyes within the sockets is employed for protection from injury (Tricas and McCosker 1984). This behavior exposes the white fibrous tissue of the eye which protects a feeding white shark from

the teeth, claws, or spines of struggling prey. We only observed this on one occasion, and it is possible that in the activity of feeding on an immobile prey item, the shark does not typically employ this behavior.

Palatoquadrate, or upper jaw, protrusion is a feeding mechanism common to most shark species and has been studied in some detail in the white shark (Tricas and McCosker 1984, Tricas 1985). It has been hypothesized to facilitate the cutting action of the teeth in the upper jaw and allowing the efficient removal of large pieces of flesh from oversized prey such as pinnipeds or a whale carcass, and/or to allow a faster speed of jaw closure (Tricas and McCosker 1984, Wilga et al. 2002). We are unsure if there is significance to the apparent lack of this behavior, though it could be an indication that jaw protrusion is a mechanism only employed against active prey. It should be noted that not all feeding bouts were witnessed while facing the shark, so it is possible that upper jaw protrusion did occur, but we were unable to observe it.

The selective preference for fat by white sharks has been noted in other scavenging observations (Pratt et al. 1982, Long and Jones 1996, Dudley et al. 2000) and has been hypothesized (Klimley et al. 1996b) to benefit the shark by providing the most energetic value per unit mass. Carey et al. (1982) estimated that a single bite of whale fat could satisfy the basal metabolism of a shark for 1.5 months. Our observations further support the existence of a preference for fatty tissue in the diet of the white shark, consistent with their preference for seals and sea lions and not birds, sea otters, and humans (see discussion, Klimley et al. 1996b). As one can see in Fig. 3, the sharks moved down the length of the whale's midsection removing the exterior layer of fat, rarely biting repeatedly into the muscle and deeper layers of tissue.

It is clear that there is much we do not know about white shark foraging behavior. The species lives in inhospitable locations, is typically out of sight underwater, and feeds opportunistically and with relative infrequency. Observations such as those we have described here pose a significant challenge to acquire, especially since the food item in question (whale carcasses) occur unpredictably in time and space. It is equally clear, given the number of sharks that appear in these instances and the voracity of their feeding, that these events represent an important resource to the species. Behavior at these times may differ appreciably from behavior during predatory encounters, reflecting the different pressures faced by the individual shark. Further observation and a more methodical approach is warranted to better elucidate the potentially critical role that whales – specifically whale carcasses – play in the life of the white shark.

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THE USE OF EASTERN SACRAMENTO VALLEY VERNAL POOLS BY DUCKS

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The published literature on the use of seasonal and semi-permanent wetlands throughout the Central Valley of California by wintering waterfowl (Anatidae) is extensive. However, few if any studies exist on the use of Sacramento Valley vernal pools by ducks. We studied ducks using vernal pools on the Vina Plains Preserve in Tehama County, California from fall 1993 through spring 2001. We conducted regular censuses of ducks on several pools during the hydroperiod in order to determine species composition and chronology of use for each species, and to quantify behavior of ducks using the pools and associated grasslands. We also collected 31 ducks from 7 species to determine food habits. Mallards, *Anas platyrhynchos*, American wigeon, *Anas americana*, and green-winged teal, *Anas crecca*, were the most common dabbling ducks using vernal pools; the ruddy duck, *Oxyura jamaicensis*, was the most common diving duck. Duck use of the pools was mostly diurnal, with the exception of nesting mallards, which often used the pools as pair-water. Ducks used vernal pools and associated uplands from January to March, with fewer observations in April as birds migrated from the area and as pools dried; maintenance and foraging were the most commonly observed behaviors of mallards, wigeon, and green-winged teal using these habitats. Chronological changes in the foraging activity of these three species combined were significant ($p=.0074$), with a decrease in foraging activity in January ($p=.00084$), and a subsequent increase in February ($p=.0031$); monthly changes in foraging activity from February through pool dessication in April were insignificant (all $p > .05$). Spikerush, *Eleocharis* spp., seeds comprised the bulk of the plant matter found in the esophagi of ducks, however, wigeon consumed mostly vegetative plant matter from grasses and forbs. Vernal pool snails, *Fossaria sonomensis*, fairy shrimp (Anostraca: *Branchinecta* spp., *Lindleriella occidentalis*), and aquatic insects were the most abundant invertebrates consumed by ducks. Overall volumetric contribution of animal matter to the diet was relatively low. The use and food habits data suggest the importance of vernal pools to ducks during late winter and early spring. California's remaining vernal pool landscapes should be protected and managed for endemic taxa and migratory waterbirds.

INTRODUCTION

The loss and degradation of winter and nesting habitat due to urbanization and agricultural expansion is a primary cause of waterfowl (Anatidae) population declines

occurring since the mid 1800s (Baldassarre and Bolen 1994). Recent estimates suggest that only 5% of California's historic wetland habitats still exist (Gilmer et al. 1982, Heitmeyer et al. 1989, Holland 1998); among the rarest and most poorly studied of these wetland habitats are California's vernal pools (Silveira 1998, Silveira 2000).

Resident and migratory waterbirds rely heavily upon wetland complexes throughout California's Central Valley (CV) during the fall and winter and to a lesser extent during the nesting season. Up to 60% of the waterfowl migrating down the Pacific Flyway during the fall use CV wetland habitats (Heitmeyer et al. 1989); the majority of these migrants winter in the Sacramento Valley. Many studies have documented waterfowl use of managed wetland complexes of seasonal and semi-permanent marshlands in California, and the use of vernal pools by waterbirds including waterfowl has been noted by several authors (Grinnell et al. 1930, Baker et al. 1992, The Nature Conservancy 1994, Silveira 1998, Silveira 2000). Nevertheless, few studies, if any, exist on the use of Sacramento Valley vernal pools by waterfowl.

Currently, many of the Sacramento Valley's remaining vernal pools occur on state or federally administered lands such as the alkali vernal pools of the Sacramento National Wildlife Refuge Complex (Silveira 2000). Other vernal pools occur on privately-owned land such as the high terrace pools at and near The Nature Conservancy's (TNC) Vina Plains Preserve in Tehama County and those found on the University of California's Jepson Prairie Preserve in Solano County. Most of the published research on these pools has focused on endemic invertebrates (Eng et al. 1990, Syrdahl¹ 1993, Gallagher 1993, Kim² 1997) and vegetation (Holland and Jain 1981, Griggs and Jain 1983, Broyles 1987, Jokerst 1993, Silveira 2000, and others).

Sacramento Valley vernal pools are well known for their invertebrate resources. Although abundant within the pools, several of the endemic crustaceans such as fairy shrimp and tadpole shrimp (Notostraca: *Lepidurus packardii*) are currently listed as endangered species (Ericksen and Belk 1999). Due to the seasonal availability of these invertebrates, it has been suggested that vernal pools may be an important source of protein and other alternative food resources for wintering and pre-migratory ducks. In addition, these vernal pools may serve as resting and foraging habitats for Pacific Flyway migrants as well as pair-water defended by male mallards during the nesting season (Heitmeyer et al. 1989, Silveira 1998).

Our objectives were to (1) determine the species composition of the duck community using high terrace vernal pools located on the eastern fringe of the Sacramento Valley, (2) estimate occurrence values for each duck species both seasonally and daily, (3) quantify the behavior of ducks using the pools and associated uplands, and (4) collect a sample of ducks for diet analysis.

¹Syrdahl, R. L. 1993. Distribution patterns of some key macroinvertebrates in a series of vernal pools at Vina Plains Preserve, Tehama County, California. M. S. Thesis, California State University, Chico. 83pp.

²Kim, S. A. 1997. Environmental factors affecting *Notonecta kirbyi* (Hemiptera: Notonectidae) predation in vernal pools at Vina Plains Preserve, Tehama County, California. M. S. Thesis, California State University, Chico. 63pp.

STUDY AREA

Our study area included several vernal pools located on the original 619 ha parcel of TNC's Vina Plains Preserve located adjacent to State Highway 99, 21 km north of Chico in southern Tehama County, California (122:03:10W 39:55:59N) (Fig. 1). This vernal pool complex occurs on a gentle rolling landscape located on a high terrace between the foothills of the southern Cascade Mountains and the floodplain of the Sacramento River. A subterranean durapan, formed from the consolidation of eroded sediments from the Tuscan basalt formation, prevents water percolation and causes rapid accumulation of water in the heavy clay loam or silt-lined pool basins (TNC 1994). Flooded pool basins support populations of green algae (Chlorophyta), blue-green bacteria (Cyanobacteria), quillworts, *Isoetes howellii* and *I. nuttallii*, water shamrock, *Marsilea vestita*, and spikerush, *Eleocharis* spp., the only emergent plants common within the pools. Dry basins support endemic plants including Orcutt grasses, *Orcuttia pilosa* and *O. tenuis*, and Hoover's spurge, *Chamaesyce hooveri*, and other plant taxa such as downingia, *Downingia* spp., coyote-thistle, *Eryngium castrense*, and cocklebur, *Xanthium strumarium* (TNC 1994). The surrounding grassland environment, comprised of four fenced pastures, supports a community of forbs and mostly exotic grasses that are grazed by cattle on a rotational basis during winter and spring (Griggs 2000). TNC also uses prescribed burns to eradicate exotic grasses such as medusa-head, *Taeniatherum caput-medusae*. Over 40 numbered pools of various sizes (up to 100 m across and 1 m in depth when fully flooded) occur within the original

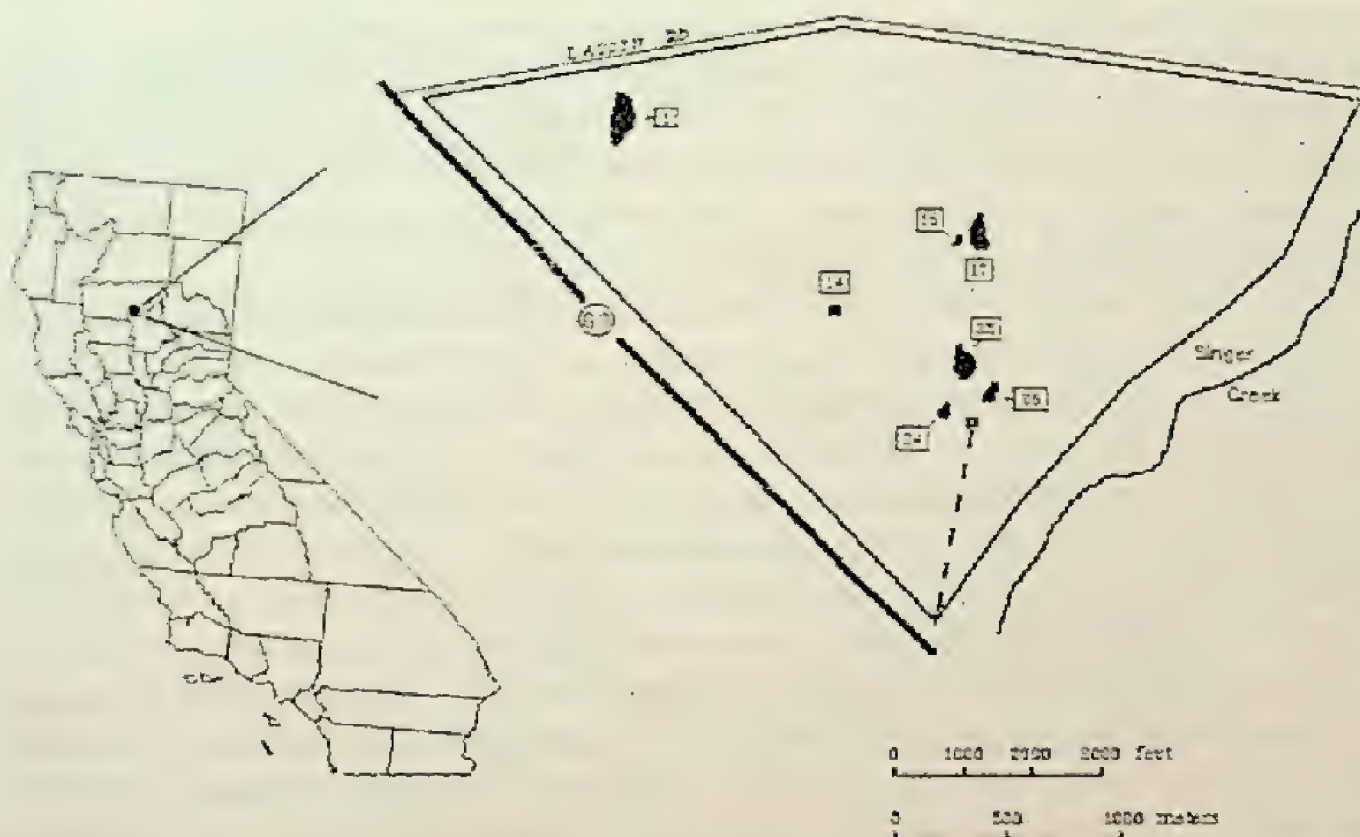


Figure 1. The original 619-ha parcel of the Vina Plains Preserve and its location in Tehama County, California (Vina Plains Preserve map from Syrdahl 1993).

preserve, with hundreds of additional smaller pools or "hog wallows". Baker et al. (1992) found that the use of vernal pools in the Santa Ana Mountains, California by waterfowl was mainly restricted to larger pools. Our preliminary observations on the Vina Plains were consistent with these findings, and as a result, our censuses were restricted to pools #1, 14, 16, 17, 34, 35, and 36, some of the largest and more accessible pools on the preserve (Fig. 1).

METHODS

We conducted duck censuses from fall 1993 through spring 1996 and from fall 1997 through spring 2001, using binoculars and a 20-60X Kowa spotting scope. A minimum of four censuses were conducted per month, although the lack of flooded pools often resulted in fewer monthly censuses. Daily census periods were as follows: (1) morning census - 0.5 h pre-sunrise to 2.5 h post-sunrise; (2) mid-day census - 3 h post-sunrise to 6 h post-sunrise; and (3) afternoon census - 2.5 h pre-sunset to 0.5 h post-sunset. A total of seven additional censuses were conducted from 4 to 1 h pre-sunrise during the 1993-1994 and 1999-2000 field seasons to detect nocturnal usage of the pools. Pools were approached on foot slowly during nocturnal censuses to listen for the sound of flushing ducks. Head lamps and a 6-volt flashlight were used to facilitate nocturnal identifications.

Censusing began in the fall or winter following initial pool flooding, and was terminated in late March or April with the dessication of one or more study pools. Complete counts were made, whenever possible, of birds on the water or in the grassland within 10 m of the shoreline. Only those ducks present at the time of arrival were censused. To avoid double counting, efforts were made to avoid flushing birds from study pools, although these efforts were often unsuccessful. When flushed, ducks were followed visually to be sure they didn't land on another study pool. Percent occurrence and range values (number of individuals) for each common duck species were calculated by census time period and month.

Duck behavior was also recorded immediately upon arrival as (1) foraging, which included diving, dabbling, or grazing, (2) maintenance, which included resting, sleeping, preening, etc., or (3) reproductive, which included courtship and activities associated with pair bond maintenance. Behavior was not quantified when ducks were observed in an "Alert" (upright with neck extended) posture, with the assumption that they were responding to our presence. Behavior was quantified by species as the percentage of all individuals engaged in the various behaviors. Mean monthly percent values for each behavior were generated for each species observed during 10 or more censuses.

We used SAS software for our statistical analyses (SAS Institute 1989). We tested for chronological (monthly) differences in foraging activity of mallards, American wigeon, and green-winged teal, combined, using ANOVA. We then used a Bonferroni approach (to maintain experiment-wise error rate at $\alpha = .05$) to test for differences in mean percent foraging values in successive months.

In addition, we collected 31 ducks of seven species between December 1997 and April 2001. All birds were collected after they had been observed foraging for a minimum

of 10 minutes (Swanson et al. 1974a). Due to the open nature of the environment, the collection method which proved the most effective was shooting following an approach from behind a pool basin ridgeline. We used a 12-gauge shotgun with #1 steel shot for our collections. Prior to collection, we obtained a Scientific Collecting permit from the California Department of Fish and Game (CDFG), and permission from TNC to collect on the preserve. Collection dates were spaced by at least a week to avoid overshooting pressure.

Gut contents were removed in the field within 5 minutes of collection, and preserved in 80% ethanol. Each individual was sexed and then aged using wing plumage criteria (Carney 1992). The remains of all ducks were then donated to the Department of Anthropology at California State University, Chico for their comparative osteological collection.

Food items removed from the mouth, pharynx, esophagus, and proventriculus were analyzed as the "esophageal sample". Esophageal contents were sorted, identified, and then quantified using volumetric displacement. Food habits data are presented taxonomically as aggregate percent and percent occurrence (Swanson et al. 1974b). The use of gizzard contents in food habits analyses will generally result in a biased assesment of diet due to the differential survivorship and identifiability of food items (Swanson and Bartonek 1970). Nevertheless, gizzard contents can provide clues as to foraging habitat type, and for that reason, forage items found in gizzards were sorted and identified.

RESULTS

We conducted 104 diurnal and 7 nocturnal censuses during this study. Censuses were initiated as early as December and as late as February, following initial flooding. Pool dessication and the termination of censuses occurred in late March and April (Table 1).

With the exception of one mallard pair flushed from pool # 17 (Fig. 1) in March 2000, no ducks were observed during nocturnal censuses. However, Canada, *Branta*

Table 1. Flooding chronology of the census pools on the Vina Plains Preserve, 1993-2001.

Year	Initial flooding ¹	Dessication ²
1993-94	Dec. 12-14, 1993	Mar. 15-17, 1994
1994-95	Dec. 15-17, 1994	Apr. 20-23, 1995
1995-96	Feb. 8-10, 1996	Mar. 29-30, 1996
1997-98	Dec. 1, 1997	Apr. 4-6, 1998
1998-99	Jan. 22-24, 1999	Apr. 20-24, 1999
1999-00	Jan. 19-21, 2000	Apr. 8-10, 2000
2000-01	Jan. 10-12, 2001	Mar. 19-Apr. 4, 2001

¹All census pools flooded

²≥1 dry census pool

canadensis, and cackling geese, *Branta hutchinsii*, were regularly observed roosting on pools at night. Because our data suggest that use of these vernal pools by ducks is primarily diurnal, we present only diurnal census data here.

In all, 15 species of ducks, 7 dabblers and 8 divers, from 4 Tribes were observed during diurnal censuses, with mallards, American wigeon, and green-winged teal being the most common taxa (Table 2). Ruddy ducks, bufflehead, *Bucephala albeola*, and ring-necked ducks, *Aythya collaris*, were the most common divers, although their numbers and rates of occurrence were relatively low (Table 2).

Table 2. Number of observations, with percent occurrence values in parentheses, for duck species during 104 censuses of the Vina Plains Preserve vernal pools, 1993-2001.

	No. (% Occur)
Tribe: Anatini - Dabbling Ducks	
American Wigeon (<i>Anas americana</i>)	39 (37.50)
Eurasian Wigeon (<i>Anas penelope</i>)	1 (0.96)
Gadwall (<i>Anas strepera</i>)	1 (0.96)
Green-winged Teal (<i>Anas crecca</i>)	24 (23.08)
Northern Pintail (<i>Anas acuta</i>)	9 (8.65)
Mallard (<i>Anas platyrhynchos</i>)	60 (57.69)
Northern Shoveler (<i>Anas clypeata</i>)	5 (4.81)
Tribe: Aythyini - Pochards	
Canvasback (<i>Aythya valisineria</i>)	1 (0.96)
Ring-necked Duck (<i>Aythya collaris</i>)	3 (2.88)
Lesser Scaup (<i>Aythya affinis</i>)	1 (0.96)
Tribe: Mergini - Sea Ducks	
Bufflehead (<i>Bucephala albeola</i>)	5 (4.81)
Common Goldeneye (<i>Bucephala clangula</i>)	2 (1.92)
Common Merganser (<i>Mergus merganser</i>)	4 (3.85)
Hooded Merganser (<i>Lophodytes cucullatus</i>)	3 (2.88)
Tribe: Oxyurini - Stiff-tailed Ducks	
Ruddy Duck (<i>Oxyura jamaicensis</i>)	7 (6.73)

Ducks were first observed using pools within 1-4 days of initial flooding, with extensive use of the pools continuing into March (Table 3). Whereas use by wigeon and teal declined in late March and April, mallard pairs continued to use the pools until they dried. Data for other duck taxa are limited, but in general, this chronological pattern held for most of these species as well.

The use of the Vina Plains vernal pools by ducks was mostly diurnal with a departure of all remaining birds shortly after sunset (Table 3). This pattern of post-sunset departure from diurnal habitats is consistent with the nocturnal foraging flights observed on state and federal refuges in the Sacramento Valley during the fall-winter

Table 3. Percent occurrence and numbers of individuals of common duck species¹ observed during 104 diurnal censuses of the Vina Plains Preserve vernal pools, 1993-2001.

Species	% Occurrence (Range)				
	Dec.	Jan.	Feb.	Mar.	Apr.
Mallard					
36 AM Censuses	20.0 (0-1)	50.0 (0-12)	66.7 (0-81)	100.0 (2-14)	80.0 (0-4)
33 Midday Censuses	60.0 (0-38)	28.6 (0-6)	87.5 (0-26)	87.5 (0-31)	100.0 (3-21)
35 PM Censuses	20.0 (0-7)	50.0 (0-8)	37.5 (0-23)	87.5 (0-14)	83.3 (0-8)
American Wigeon					
36 AM Censuses	0.0 (0)	37.5 (0-36)	77.8 (0-21)	77.8 (0-73)	20.0 (0-2)
33 Midday Censuses	40.0 (0-24)	28.6 (0-30)	37.5 (0-151)	87.5 (0-45)	40.0 (0-8)
35 PM Censuses	0.0 (0)	0.0 (0)	37.5 (0-77)	87.5 (0-41)	0.0 (0)
Green-winged Teal					
36 AM Censuses	20.0 (0-8)	37.5 (0-43)	22.2 (0-385)	33.3 (0-12)	0.0 (0)
33 Midday Censuses	60.0 (0-3)	14.3 (0-10)	12.5 (0-6)	50.0 (0-29)	0.0 (0)
35 PM Censuses	20.0 (0-19)	0.0 (0)	0.0 (0)	50.0 (0-14)	16.7 (0-2)

¹Those taxa observed during 10 or more censuses, 1993-2001.

hunting season (Heitmeyer and Raveling³ 1988).

Maintenance and foraging were the most common behaviors of mallards, American wigeon, and green-winged teal using the Vina Plains vernal pools during the winter and spring hydroperiod (Table 4). Monthly changes in foraging activity for these three species combined were significant ($F_{4,7} = 8.7475$, $p = .0074$) (Table 4). Foraging activity decreased from December to January ($t = 4.96$, $df = 7$, $p = .00084$), and increased in February ($t = 3.973$, $df = 7$, $p = .0031$). No significant change in foraging activity was observed from February to March ($t = 0.198$, $df = 7$, $p = 0.4243$), or from March to the time of pool dessication in April ($t = 0.788$, $df = 7$, $p = 0.2283$) (Table 4). Although we did not test for chronological differences in the foraging activity of each species independently, our data suggest the same chronological pattern for mallards, wigeon, and teal (Table 4). Although dabbling and diving were the most commonly observed duck foraging behaviors, wigeon shifted to an upland grazing strategy near vernal pool shorelines by mid-January, as new-growth grasses and forbs became available.

We collected 7 mallards (1 immature male, 3 adult males, and 3 immature females), 11 American wigeon (4 immature males, 4 adult males, and 3 adult females), 3 green-winged teal (1 immature male, 1 adult male, and 1 immature female), 7 ruddy ducks (3 immature males, 1 adult male, 1 immature female, and 2 adult females), 1 adult male ring-necked duck, 1 adult male bufflehead, and 1 adult male common merganser for our food habits analysis (Tables 5, 6). With the exception of the bufflehead which was collected in December, all ducks were collected in January ($n = 6$), February ($n = 2$), March ($n = 17$), and April ($n = 5$).

Plant matter was present in all mallard and wigeon esophagi; spikerush seeds and the vegetative parts of grasses and forbs comprised the bulk of the plant material in their diets respectively (Table 5). Spikerush seeds accounted for the greatest percentage of the plant material consumed by teal as well. Vernal pool snails and the immature and adult stages of aquatic insects were the most abundant invertebrates in the esophagi of dabbling ducks, although the overall volumetric contribution of animal relative to plant matter was low (Table 5). However, the esophageal sample from one immature female mallard collected in March 1998 contained over 300 snails. Plant and animal matter comprised 75.1% and 24.9% of the ruddy duck diet respectively, with spikerush seeds and fairy shrimp (Anostraca) being the most abundant food items (Table 6). Food habits data for other divers are extremely limited (Table 6), but provide evidence of successful foraging efforts on vernal pool vegetation and invertebrates.

Gizzard contents also provided evidence of foraging within vernal pools as well as other disjunct wetland habitats. For example five of seven ruddy duck gizzards contained the remains of vernal pool tadpole shrimp; only two of these five birds had tadpole shrimp in their esophagi. Tadpole shrimp remains were also present in the gizzard of the single ring-necked duck. As all ruddy and ring-necked ducks collected

³Heitmeyer, M. E., and D. G. Raveling. 1988. Winter resource use by three species of dabbling ducks in California. Department of Wildlife and Fisheries Biology, U.C., Davis, California (Final Report prepared for Delta Waterfowl and Wetlands Research Station, Portage La Prairie, Manitoba, Canada. 201pp.

Table 4. Percent of all mallards, American wigeon, and green-winged teal, observed during daylight hours on the Vina Plains vernal pools (1993-2001) engaged in various activities.

Month, Activity, Number of individuals, Number of censuses ¹	Percent of all Individuals Observed		
	Mallards	American Wigeon	Green-winged Teal
December			
Foraging	30.7	100.0	90.0
Maintenance	69.3	-	10.0
Reproductive	-	-	-
Total %	100.0	100.0	100.0
Number of Birds	75	9	30
Number of Censuses	5	1	3
January			
Foraging	13.3	27.3	20.6
Maintenance	86.7	54.5	79.4
Reproductive	-	18.2	-
Total %	100.0	100.0	100.0
Number of Birds	83	33	34
Number of Censuses	9	3	2
February			
Foraging	28.2	78.5	79.1
Maintenance	71.8	20.1	20.9
Reproductive	-	1.4	-
Total %	100.0	100.0	100.0
Number of Birds	156	293	344 ²
Number of Censuses	9	7	3
March			
Foraging	25.4	84.3	82.5
Maintenance	71.6	13.7	17.5
Reproductive	3.0	2.1	-
Total %	100.0	100.1 ³	100.0
Number of Birds	134	388	40
Number of Censuses	19	12	8
April			
Foraging	47.5	100.0	-
Maintenance	52.5	-	-
Reproductive	-	-	-
Total %	100.0	100.0	-
Number of Birds	61	40	-
Number of Censuses	7	2	-

¹Number of censuses during which behavioral data were collected.²Total of 344 teal includes one estimate of 300 birds on pool #17 (February 10, 1996); all other numbers in this table are the result of direct counts.³Error due to rounding.

Table 5. Food habits of dabbling ducks (n=21) collected on vernal pools at the Vina Plains Preserve, Tehama County, California, 1997-2001.

Food Item	N = 7 Mallard		N=11 American Wigeon		N=3 Green-winged Teal	
	V ¹	O ¹	V	O	V	O
Plant						
Cyperaceae						
<i>Eleocharis</i> spp. – seed	45.2	71.4	9.1	18.2	33.3	66.7
<i>Eleocharis</i> spp. – vegetative	7.1	14.3	-	-	-	-
Poaceae						
Unid. Seed	tr ²	14.3	1.3	9.1	-	-
Unid. Vegetative	14.3	14.3	46.1	72.7	-	-
Unid. Plant – Seed	7.1	42.9	22.7	27.3	tr	33.3
Unid. Plant – Vegetative	0.2	42.9	16.2	45.5	-	-
Total Plant	74.0	100.0	95.4	100.0	33.3	66.7
Animal						
Gastropoda						
<i>Fossaria sonomensis</i>	13.8	14.3	1.5	9.1	33.3	33.3
Crustacea						
Ostracoda	tr	28.6	-	-	tr	33.3
Notostraca						
<i>Lepidurus packardii</i>	0.2	14.3	-	-	-	-
Copepoda	-	-	tr	9.1	-	-

Insecta						
Coleoptera						
Dytiscidae	tr	14.3	-	-	-	-
Dryopidae	7.1	14.3	-	-	-	-
Unknown	4.8	14.3	-	-	-	-
Unid. Insecta	-	-	3.1	18.2	-	-
Total Animal	26.0	42.0	4.6	45.5	33.3	33.3

¹V = Aggregate percent volume, O = percent occurrence.

²tr = trace amounts < 0.1 ml; trace items not included in calculation of aggregate percent volume.

Table 6. Food habits of diving ducks (n=10) collected on vernal pools at the Vina Plains Preserve, Tehama County, California, 1997-2001.

Food Item	N = 7		N=1		N=1		N=1	
	Ruddy Duck		Ring-necked Duck		Common Merganser		Bufflehead	
	V ¹	O ¹	V	O	V	O	V	O
Plant								
Cyperaceae								
<i>Eleocharis</i> spp. – seed	53.7	71.4	-	-	-	-	-	-
Poaceae								
Unid. Seed	15.9	28.6	100.0	100.0	-	-	-	-
Unid. Plant – Seed	3.3	57.1	-	-	-	-	-	-
Unid. Plant – Vegetative	2.2	14.3	-	-	-	-	-	-
Total Plant	75.1	100.0	100.0	100.0	-	-	tr ²	100.0
Animal								
Nematoda	-	-	-	-	100.0	100.0	-	100.0
Gastropoda								
<i>Fossaria sonomensis</i>	1.6	14.3	-	-	-	-	-	-
Crustacea								
Anostraca	11.5	42.9	-	-	-	-	-	-
Notostraca								
<i>Lepidurus packardii</i>	0.3	28.6	-	-	-	-	-	-
Copepoda	-	-	-	-	-	-	-	-

Insecta								
Coleoptera								
Dytiscidae	1.6	14.3	-	-	-	-	-	-
Hemiptera								
Corixidae	-	-	-	-	-	-	tr	100.0
Unid. Insecta	tr	14.3	-	-	-	-	-	-
Total Animal	24.9	71.4	-	-	100.0	100.0	tr	100.0

¹V = Aggregate percent volume, O = percent occurrence.

²tr = trace amounts < 0.1 ml; trace items not included in calculation of aggregate percent volume.

during this study were present and foraging at the time of our arrival, we suspect that these shrimp were likely consumed at either the collection pools or other pools on the Vina Plains. Seeds of willow smartweed, *Polygonum lapathifolium*, were found in the gizzards of the single bufflehead, three ruddy ducks, one American wigeon, and three mallards, and watergrass, *Echinochloa crus-galli*, seeds were found in the gizzard of a male mallard. These plant species do not occur on the Vina Plains Preserve, but are associated with valley marshlands and agricultural (i.e., rice) habitats. Their presence in gizzards suggests nocturnal foraging in these adjacent habitat types.

DISCUSSION

Eastern Sacramento Valley high-terrace vernal pools are used diurnally by most of the duck species that winter in the CV (Table 2). Although Heitmeyer and Raveling (1988) found a decrease in night foraging flights away from diurnal habitats on the Sacramento National Wildlife Refuge following the end of the hunting season, we found no evidence of nocturnal usage of these pools by ducks during the hydroperiod other than as pair-water by nesting mallards. Also, the presence of watergrass and smartweed seeds in several duck gizzards provides additional evidence of nocturnal foraging in other wetland habitats.

The most common and abundant duck species using vernal pools in our study area were mallards, American wigeon, and green-winged teal (Tables 2, 3). Baker et al. (1992) found these three species, along with cinnamon teal, *Anas cyanoptera*, to be the most common ducks using vernal pools on the Santa Rosa Plateau in Riverside County. Silveira (1998) also included the cinnamon teal as well as the wood duck, *Aix sponsa*, on the list of CV vernal pool ducks. We suspect that the lack of cinnamon teal and wood duck observations on the Vina Plains is due in large part to the proximity of these pools to valley marshland complexes and riparian habitats preferred by cinnamon teal and wood ducks respectively (Bellrose 1980).

We observed regular diurnal use of vernal pools by ducks during the winter and early spring months, with a significant increase in the foraging activity of mallards, American wigeon, and green-winged teal beginning in February (Tables 3, 4). These observations are consistent with suggestions that vernal pools may be most important to ducks dispersing from dense Fall-Winter aggregations following pair-bonding and the possible depletion of winter food resources (Heitmeyer and Raveling 1988, Silveira 1998), and also that waterfowl spend more time foraging prior to spring migration and reproduction (Drobney 1980, McLandress and Raveling 1981). This pre-migratory hyperphagia follows a period of winter weight loss due to the energetic costs of thermoregulation, courtship (e.g., courtship flights), pair-bond maintenance (e.g., mate defense), and molt. As a result, ducks require high energy foods such as fruits and seeds needed to restore endogenous reserves prior to migration, and invertebrates, which provide needed protein and calcium (e.g., crustaceans and snails) for plumage development and egg production (Heitmeyer and Raveling 1988). Although we lack the necessary food habits data needed to make comparisons among the sexes, our data show that energy and protein-rich food items are being consumed by both male and

female dabbling and diving ducks while foraging within these vernal pools (Tables 5, 6). Also, upland grasses and forbs in an early stage of phenological development were regularly consumed by wigeon during this study (Table 5). In addition to being more digestible (Raveling 1979, Buchsbaum et al. 1986), this new-growth or recently grazed herbaceous material is relatively high in protein needed by wigeon during this phase of their annual energy cycle (Mattson 1980).

Future research focusing on the differential utilization of Central Valley vernal pools by male and female ducks, both chronologically and with respect to diet, would provide additional insight into the relative importance of these unique wetland habitats. Additionally, the use of vernal pools and associated grassland habitats by geese (Anserini), tundra swans, *Cygnus columbianus*, and other waterbirds (e.g., shorebirds) would fill a significant gap in the vernal pool literature.

RECOMMENDATIONS

Due to the potential importance of these ephemeral vernal pool wetlands to wintering, molting, migrating, and nesting ducks, we feel that management and conservation issues relating to California's remnant vernal pool habitats should be given additional attention in the future (Silveira 1998, Griggs 2000). Continued management of state, federal, and privately owned vernal pool landscapes through the wise use of prescribed burns, rotational grazing, restrictions to unregulated public access, etc., as well as the development of new conservation easements (e.g., TNC's conservation easement on the Earl Foor Ranch, located immediately north of the Vina Plains Preserve) are necessary in order to protect these important historic wetlands.

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USING FLUSHING COUNTS AND PLUMAGE DEVELOPMENT TO ASSESS JUVENILE PRODUCTION IN PHEASANTS

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ABSTRACT

We have developed a new method for evaluating annual production of ring-necked pheasants, *Phasianus colchicus*. It is based on distinguishing juveniles 8-10 weeks old from adult hens by plumage development, primarily by the different length and shape of the tails as observed in flight. Sampling is by standard transect flushing counts, as used for obtaining pheasant sex ratios, to determine the ratio of juveniles per adult hen. The counts need to be properly timed, made at approximately 8-10 weeks after the peak of the pheasant hatch. For California's Central Valley the counts should be conducted from late July to mid-August. With these counts being made when the young average nearly a month or more older than with roadside or other brood counts, this method is a more direct and reliable indicator of juvenile recruitment to the fall population. Furthermore, it can be applied to local populations in smaller fields or areas that are without an adequate road-sampling pattern and thus unsuitable for use of roadside brood counts.

INTRODUCTION

The new method was developed in conjunction with an evaluation of the Diversified Upland Habitat Unit (DUHU) system of managing habitat. This field-testing was carried

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out in 2001-2003 on the Grizzly Island Wildlife Area (GIWA) of the California Department of Fish and Game (CDFG). The process consisted primarily of comparing pheasant, *Phasianus colchicus*, production from a test area under DUHU management with that from a Comparison (control) Area (CA) as conventionally managed at GIWA.

Productivity was to be measured mainly by determining the average number of juveniles reared per hen in each of the test areas. However, there was no standard or proven method for objectively assessing pheasant production from such small areas, each test area being approximately 30-35 ha (75-80 acres) in size.

The method in the study plan was logical but unproven. Average production per hen was to be determined from a breeding-population sample of pheasants in each test area that had been captured, radio-tagged, and monitored for study purposes. Locating, surrounding, and flushing the radio-tagged hens with their broods in each test area would enable counting numbers of juveniles per hen. The timing for such flushing counts was when the brood was approximately 6 weeks old. At this age the juveniles were small enough to be distinguished readily, and shortly before they started leaving the hen.

However, this method proved unsatisfactory. Many hens refused to flush and separate from their broods. By the time this was evident, brood members tended to be scattered and, if found, possibly mixed with other broods in the vicinity. Thus, most brood sizes could not be determined reliably by this procedure. We needed to develop a new method of evaluating pheasant productivity suitable for the circumstances.

STUDY AREA

The productivity evaluation was conducted on the Grizzly Island Wildlife Area (GIWA) in Suisun Marsh, south of Fairfield in the western Delta region of central California. The approximately 3,480-ha (8,600-acre) wildlife area was devoted primarily to managed estuarine marsh and other wetlands. However, the area also contained significant areas of uplands with an existing population of wild pheasants. The DUHU and CA were both located within the major block of uplands, approximately 607-ha (1500-acre) in size.

METHOD

A new method to assess pheasant productivity accurately needed to measure the numbers of young reared per hen at the oldest juvenile age feasible. This preferably would be after the higher mortality period typical of the chick and poult stages of ringneck juvenility (Stokes 1954). In addition to assessing actual production more accurately, such older-aging results would be more reliable indicators of juvenile recruitment to the fall population and more useful in determining population dynamics.

Therefore, we used plumage development as previously determined in California in order to distinguish older age classes of juvenile pheasants from adults. Plumage characteristics are one of the most useful ways of distinguishing young from old birds, in turkeys by tailfeather length (Dimmick and Pelton 1996).

Mature ring-necked pheasants characteristically have long, pointed tails, especially in the males. The hens are smaller and have shorter tails, although approximately as long as their bodies. Juvenile pheasants do not grow these longer tailfeathers until the last stage of their assuming adult plumage, tending to be distinguishable through much of their pre-adult life by their shorter tails.

These observations were made or confirmed during the Sutter Basin studies in 1952-1957 that were supervised by the senior author (Hart unpublished data, Mallette and Harper 1964). In this Sacramento Valley investigation, >10,000 wild juveniles and >3,500 adult pheasant hens were captured and examined. Hens were secured at the same time as juveniles of various ages, so that plumage development could be compared directly. Also, correlation of plumage status with juvenile ages of approximately 6-16 weeks was accomplished with aging by the primary wingfeather molt (Buss 1946).

The Sutter Basin studies confirmed that the longer growth of central tailfeathers in ringnecks generally occurred at approximately 12 to 16 weeks of age. This was in about the last month of the sub-adults fully developing adult plumage. Prior to that period of more rapid plumage growth, tails of juvenile pheasants of both sexes were relatively short. In juveniles approximately 8-10 weeks old, tails were about a third to half as long as those of adult hens.

In addition, tails differed in shape by age-class. With longer central tailfeathers, the mature hen's tail was pointed or wedge-shaped. Lacking these adult tailfeathers, the juvenile tails at 8-10 weeks old typically had a squared-off or approximately fan-shape appearance.

These distinctions are difficult to make accurately in birds observed on the ground, in part because the tail is not spread as in flight. Also, individual birds often cannot be observed adequately for tail length due to being partially screened by vegetation or other birds. In addition, birds mixing and moving about, in and out of cover, may lead to confusion and potential duplication. Thus, obtaining reliable age ratios by ground observations using plumage development was not feasible in the study circumstances, and probably rarely will be elsewhere. The solution adopted was using flushing counts to enable better observation of the tails in flight.

At approximately 8-10 weeks old, juveniles of both sexes resemble adult hens in color, all generally appearing mottled brown and tan. Some older and larger juveniles also are approaching the body size of smaller-than-average adult hens, so that size may not be easily distinctive then. However, the comparative length and shape of tails distinguished such juveniles from adults readily in flight.

In actual use in the field, this process is simpler than may be perceived from the description. As pheasants are flushed, observers focus on the tails of the brownish birds. The colorful, adult roosters are irrelevant to the process and may be ignored, unless a count is being kept of the total number of birds flushed.

For the brownish pheasants, a quick, visual determination is made of short or long tail, which usually can be made as the bird flushes. If necessary, confirmation can be made by tail shape. The flushing and flight paths typically enable viewing from differing angles, usually at some point silhouetted against the sky, for clarification or confirmation as needed.

For consistent and comparative sampling, we combined this aging technique with transect flushing counts. These were conducted in the same manner as long-used in California for making pheasant sex-ratio counts (CDFG² 1959). Sex ratios are required for estimating populations by change-in-ratio methods (Kelker 1940, Selleck and Hart 1956). These methods have been used in population monitoring on pheasant study areas in California and elsewhere (Harper et al. 1951, Stokes 1954). We simply adapted the flushing-transect method of sampling to obtain age-ratios instead of sex-ratios.

The timely period for making such counts in the study area was the last week of July through the first 2 weeks of August. This period falls approximately 8-10 weeks after the usual peak of the pheasant hatch, which is in or about the last week in May in most of California's main pheasant range (CDFG² 1959, Brueggemann and Hart³ 2003). Users of this method in regions where the peak of the hatch differs should make appropriate adjustments for timing of the counts.

The flushing-transect technique uses drivers, preferably with trained flushing dogs, to flush birds, with blockers to observe pheasants that run or flush well ahead. Transects are planned to yield representative samples of desired areas. Average production/hen is indicated by the age ratio obtained from the flushed sample.

Experienced observers may be able to extend or vary this count period slightly, which may be appropriate with early or delayed hatch periods. However, they should be alert to the key for when the suitable time-frame for such counts has ended. This is when the larger or earlier-hatched juvenile roosters tend to become more difficult to distinguish in flight from adult hens. Due to their developing to be larger and longer-tailed, juvenile roosters reach this overlap appearance in body size and lengthened tail earlier than young hens. However, as this overlap stage begins, these young roosters usually can be distinguished by the patchy character of the darker and more colorful adult plumage they also are assuming then. Another clue is their typical immature, squealing cackle often emitted as they flush, distinctive from a mature rooster's more robust cackle. Whether in the normal or an extended count period, encountering appreciable numbers of such maturing young roosters becoming difficult to distinguish from mature hens should signal ending the counts.

This method may not be successful in rare instances where extremely dense cover makes pheasants too difficult to flush. This can occur even with using trained dogs, possibly due in part to poorer scenting conditions in the typical heat of the summer counting-period. However, using such trained dogs typically increases efficiency by their being more active and usually penetrating denser cover more easily than most humans. Also, their ability to scent and chase running birds typically results in finding and flushing more pheasants, thereby increasing sample size with less human effort. Furthermore, there has been no evidence of differences in sex or age ratios obtained with and without use of dogs, so that comparability is not affected.

²CDFG (California Department of Fish and Game). 1959. Pheasant management handbook. Wildlife Management Branch, Sacramento, California, USA.

³Brueggemann, S. J. and C. M. Hart. 2003. Radiotelemetry studies of ring-necked pheasant reproduction on Mendota Wildlife Area, California. Wildlife Programs Branch Administrative Report No. 2003-1. California Department of Fish and Game, Sacramento, California, USA.

Counts should not be started too early in the morning in order to avoid heat or for convenience. Pheasants tend to be scattered then in their morning feeding and watering activities, which can reduce sampling efficiency. They preferably should be given undisturbed opportunity to complete their normal early-morning routine and later concentrate in their usual loafing cover. When so concentrated and with sampling transects planned to include known or likely loafing cover, counting efficiency usually can be increased appreciably. This may require not starting counts before about 0800.

Due to these counts being made during the usual hot-weather period in summer, appropriate care should be taken to avoid dehydration or over-heating of participating personnel and dogs in the field. In areas where rattlesnakes are present and active during the count period, use of dogs may not be prudent, and protective gear should be worn by field personnel.

DISCUSSION

Annual pheasant production, or an index thereto, commonly has been estimated by use of roadside brood counts made from vehicles. This method evolved out of an old practice that originated in the Midwest and may still be used in some areas. The system consisted of having rural mail-carriers record numbers of pheasants seen in the course of their mail deliveries. In part, this worked reasonably well because there typically was a road on each section line, forming a regular sampling pattern over extensive areas.

In evaluating this method for application in California, the former pheasant research project (PR-W-22R) of CDFG recommended that the method be used on large areas of approximately 161^2 - 322^2 km (100^2 - 200^2 miles). In such extensive areas, hens and broods were counted by observations in slowly driving at least 322 km (200 miles) on an adequate sampling pattern of secondary roads (CDFG² 1959). Results from use of this method under prescribed conditions were later evaluated for the Central Valley (Hart⁴ 1990). Here the annual trends in chicks observed per unit of distance driven correlated well with those from the pheasant bag as reported in the Department's annual game take survey. But apparently for lack of a better method, the roadside counts have been used also on smaller State and Federal or similar wildlife areas that do not meet the established standards. Thus, validity of such results may vary with local circumstances and be questionable.

Furthermore, any method of counting young pheasants per brood did not meet desired standards for the new method. Pheasant chicks are precocial and brooded by the hen. This has enabled counting young in broods in the company of hens, where feasible, as a standard method of determining mortality/survival at an early age. However, this method is valid only as long as broods remain with the hen, before the age of brood break-up. This stage of juvenile maturation where young pheasants start

⁴Hart, C. M. 1990. Management plan for the ring-necked pheasant in California. Wildlife Management Branch, California Department of Fish and Game, Sacramento, California, USA.

leaving the hen, becoming independent and intermixed, usually begins at approximately 7 weeks of age (Stokes 1954). Thus, counted size of broods >6 weeks old cannot be assumed valid indicators of survival, productivity, or recruitment.

This new technique offers a superior and more universally appropriate method of assessing such annual pheasant productivity. It can be applied feasibly to fairly small or roadless production units. Also, larger areas can be evaluated through use of this method with a representative pattern of sampling transects, irrespective of presence or absence of roads.

In addition, the new method provides a better and more direct measure of production from the local breeding population. Production is indicated by the average number of juveniles per adult hen, determined at older juvenile ages than with brood counts. Also, the numbers of birds flushed can directly provide a minimum (not all birds are flushed) production or population estimate per unit of area when related to the area of the sampling transects. In contrast, with roadside brood counts the usual product, number of chicks observed per unit of distance driven, is only an index to productivity, and does not relate directly either to production per hen or per unit of area.

Under favorable circumstances, successful counts have been made by a single person with use of flushing dogs. For example, in about 2 hours during 2003, a co-author with two flushing dogs sampled transects in three fields making up an approximately 162-ha (400 acre) managed unit. Pheasants classified totaled 115, including 24 adult hens and 85 juveniles for a ratio of 3.5 J/AH. Similar results from like effort have been achieved elsewhere.

With conventional use of the counts in 2005, production was compared from 23 areas in or adjacent to the Sacramento Valley. These included eight areas, totaling approximately 291 ha (720 acres), that were DUHU-managed to maximize juvenile survival. In these managed units, the counts produced a sample of 820 pheasants with a classified ratio of 9.3 J/AH. In the 15 unmanaged areas, aggregating approximately 760 ha (1,878 acres), similar effort classified a 112 pheasant sample having a ratio of 2.8 J/AH. The differences in pheasant production in the two types of areas were obvious.

Such counts also can produce information indicative of poor nesting success or brood survival. These are indicated by observing significant numbers of juveniles that are obviously smaller and younger than appropriate for the count timing. This can be due to renesting caused by nest depredation or destruction, or to brood loss soon after hatching. Although such renesting helps to compensate for loss of initial nests and broods, clutch sizes are smaller and chick survival typically poorer, so that pheasant productivity generally is lower under such circumstances (Stokes 1954, Mallette and Harper 1964).

This method now has been in use for approximately 5 years and generally has produced good results in suitable circumstances, including the 3 years of the GIWA evaluation. It also is being used by CDFG for a similar evaluation of California's first project under the Conservation Reserve Enhancement Program (CREP), a relatively new program for cropland set-aside under provisions of the Federal Farm Bill (P. Lauridson, unpublished data).

MANAGEMENT IMPLICATIONS

This new technique adds a valuable tool for pheasant management and research. It enables more positive and definitive monitoring or assessment of juvenile production. It measures survival at an older age that gives a better and more direct indication of juvenile recruitment to the fall population. Its timely use tends to avoid undesirable breaking-up of broods from making brood counts while chicks are younger and still dependent on the hen. It enables sampling of areas too small or limited in road pattern for valid use of roadside brood counts. Larger areas devoid of such a road network can be sampled by an appropriate pattern of flushing transects in representative fields. In favorable circumstances the technique can be used for a given area by a single individual in a single day or two. On managed areas where analysis of roadside brood count data has shown poor correlation with hunting season bag or other relevant information, consideration should be given to changing to this new method.

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LIGHT-TRAPPING OF LARVAL AND JUVENILE NORTHERN PIKE, *ESOX LUCIUS*, FROM LAKE DAVIS, CALIFORNIA SPRING 2003

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ABSTRACT

For the purpose of developing new management options for removal of young-of-the-year northern pike, *Esox lucius*, from Lake Davis, Plumas County, California, light-trapping was conducted using Plexiglas quatri-foil light-traps. Traps were deployed in a known pike spawning area to determine if emerging northern pike would respond photo-taxically and enter traps. Light-trapping efforts were spread over a 1-month developmental period. A total of 21 pike was caught using the light-traps in 7 total nights of trapping from 24 April 2003 to 24 May 2003. Light-trapped pike seemed to begin responding at a time frame of development just after yolk absorption ceased and predation was required. Light-trapped pike averaged 13.3 mm total length (TL). Traps used either battery-powered Krill[®] lamps, or Cyalume photochemical lightsticks as attractants. Neither light source attracted a reasonable catch rate of pike to warrant this procedure in the Lake Davis management Plan.

INTRODUCTION

Unfortunately for Lake Davis resource management, this State Water Project reservoir offers ideal habitat and plentiful food resources to sustain a reproducing northern pike, *Esox lucius*, population. Lake Davis has traditionally been a State-managed, put-and-take rainbow trout, *Oncorhynchus mykiss*, fishery, but since the discovery of this non-native piscivore in the reservoir, stocking of hatchery-raised rainbow trout has been significantly reduced.

In February 2000, 'Managing Northern Pike At Lake Davis: A Plan for Y2000' (hereafter known as Plan) was developed by the California Department of Fish and Game (CDFG), along with local community members, to manage an illegally-introduced northern pike population in Lake Davis (Fig. 1).

To counteract reproductive success of northern pike, and in an attempt to keep the population size as small as possible, the Plan implemented many control and containment

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Figure 1. Lake Davis, Plumas County, California.

strategies within the reservoir, including: gill-netting, block-netting, electro-shocking, purse-seining, beach seining, detonation cord, and stocking of predatory brown trout, *Salmo trutta*. Additionally, within the Plan, the CDFG proposed monitoring that includes egg and larval fish sampling; by determining spawning sites and monitoring early development, control methods for these vulnerable larval and juvenile life stages might be developed.

This study tested light-trapping as a control method in a known northern pike spawning area, South Mosquito Slough, and attempted to capture and remove newly emerging northern pike that respond photo-tactically to light in darkness. Once fish enter light traps they can be removed from the Lake's population. If large enough numbers of larval and juvenile northern pike (Fig. 2) can be removed by this method, it may negatively affect the species' annual recruitment and improve management of the fishery for rainbow trout.



Figure 2. Actively feeding northern pike (18.5mm) with engorged stomach, not yolk sac.

Zigler and Dewey (1995) determined that larval and juvenile northern pike were photo-positive and respond photo-tactically to light sources in Plexiglass light-traps, both in a pond and hatchery raceways. They concluded that light traps should effectively sample age-0 northern pike for at least 6 weeks after emerging. In a laboratory setting, Girsá (1969) also found that age-0 northern pike were photo-positive and "remained or swam about under a lamp" above an aquarium when the light was introduced after total darkness. These studies reveal northern pike's attraction and movement towards light sources, in relative darkness, at early developmental stages.

At Lake Davis, I tested the use of Plexiglas light traps with two different types of light sources to capture and remove age-0 pike from a known spawning area, South Mosquito Slough, within their first 6 weeks of development. If light-trapping was successful, resource managers could capture and destroy young-of-the-year northern pike with this additional strategy (Marchetti et al. 2003).

METHODS

To determine the location of larval pike in South Mosquito Slough, sampling with a fine mesh D-net was conducted during the day by dragging it just above the substrate

while drifting across South Mosquito Slough in a boat. This was done until the net was obstructed by filamentous green algae, which was utilized as cover by these larval fish. Once areas were discovered that contained age-0 pike, transects were set up by pounding two t-posts into the slough bottom, roughly 15 m apart in 1-m to 1.5-m deep water, and stringing a 3/8-inch nylon rope between them. Three quatri-foil traps (Kilgore 1991) were placed on each transect 3 m apart, suspended just below the surface. The three traps each had a different type of light source: 1) a single chemical lightstick (Cyalume Lightsticks, green color), 2) two battery-powered krill lamps (Kriana Corporation, 360 green), and 3) four of the same battery-powered krill lamps.

Up to three transects, a maximum of nine light traps total (three/transect), were placed in South Mosquito Slough weekly from 24 April 2003–24 May 2003. Traps were set at dusk, illuminated immediately, and picked up the next morning shortly after daybreak. Contents of light traps were field examined for larval/juvenile pike on site and placed in 5% formalin for later sorting in the laboratory.

In the laboratory, northern pike were measured to the nearest 0.5 mm total length (TL), rated according to Snyder's "Terminologies for larval fishes" (Snyder 1976), and sorted into two categories, (1) actively feeding, or (2) still absorbing the yolk sac.

Physical data was also taken in South Mosquito Slough throughout the study. Temperature (°C), electro-conductivity (us), turbidity, pH, and dissolved oxygen (mg/L) were measured before each sampling period. All physical measurements were taken from surface water.

RESULTS

Light-traps were found to elicit very little response from larval and juvenile northern pike. A total of 21 pike was caught in 7 nights of trapping using 3-9 light traps per night. All light-trapped pike were collected on two consecutive nights, 1 and 2 May 2003. Pike sampled by D-net during this 2-day period (n=46) had an average total length of 13.3 mm. Several individuals showed signs of active feeding for the first time in the study.

D-netting of larval and juvenile pike for site determination, and growth and developmental stage monitoring, yielded 97 pike (9.5 mm to 22.0 mm) over the study period. This capture method was a reliable way to sample the young-of-the-year pike population in South Mosquito Slough until aquatic macrophyte growth inundated the study area.

Physical data suggests that temperature may affect growth rate. As surface water temperature increased from 15.5 °C to 19.9 °C in 1 week, increase in TL averaged 12.7 mm. Previously measured fish increased 5.4 mm as temp moved from 6.6 °C to 15.4 °C over the 4 previous weeks. (Temperature would seemingly increase prey abundance as well, which was an unexplored factor for growth in this study.) Overall, the slough kept a relatively constant electro-conductivity between 60-73 us, turbidity never exceeded 2.01 ntu, pH ranged from 8.2-9.2, and dissolved oxygen was 9.0 to 11.3 mg/

L

DISCUSSION

Light-traps are useful tools in sampling some species of larval fish (Dewey and Jennings 1992, Kissick 1993, Gehrke 1994). Previous studies by Girsal (1969) and Zigler and Dewey (1995) demonstrated larval and juvenile pike attraction to light and their susceptibility to capture in light traps.

Using Plexiglas quadri-foil light-traps, Zigler and Dewey (1995) showed that catches of larval pike in lighted traps were significantly greater than catches in control traps. Most success was in a raceway setting, and was achieved over three different developmental stages: protolarvae (11-17 mm), mesolarvae (15-20 mm), and juvenile (25-66 mm). During these raceway tests, up to 46.5% of the total number of fish were caught. One reason for this high success rate, compared to this Lake Davis study, could be attributed to fish densities used during raceway trials.

Zigler and Dewey (1995) used fish densities (mean=1506 fish/m³) presumably greater than in South Mosquito Slough. Young-of-the-year northern pike were more broadly distributed due to the size of the study site (approximately 10 surface-acres) and adult broadcast spawning behavior. This was evident by the amount of effort it took to D-net fish from the bottom of the slough. It took roughly 1 hour to net 15-20 immobile fish early in the study. If densities were higher, or approached the density used by Zigler and Dewey (1995), fish would possibly have been more easily caught.

Another difference was the trapping methodology. In the aforementioned study, traps were set for 2 hours, from 2000-2200 hours. At Lake Davis, due to this study's primary limitations (weather, combined with the boating distance between the Lake's only accessible boat ramp and the study site in darkness), traps were left to fish overnight. Leaving the traps in all night may have allowed pike to enter the traps and also to exit them before traps were retrieved.

The difference of experimental settings may also have contributed to the lack of light-trapping success at Lake Davis compared to Zigler and Dewey's raceway tests. The natural setting of South Mosquito Slough offered young of the year pike a seemingly unlimited food supply, as zooplankton were extremely abundant in traps. One possible explanation could be that pike were satiated and did not enter light traps.

My observations beg the question: do larval northern pike actively forage at night and could a mutual reaction between larval northern pike and zooplankton to light-stimulus reflect a naturally selective feeding strategy for larval fish, as pike have evolved to depend on zooplankton for their earliest development? Helfman et al. (1997) reported that visual anatomy, light sensitivity, and range of wavelengths detected generally all develop with age and are intricately linked with food acquisition and predator avoidance. The fact that larval pike were successfully trapped in this Lake Davis study at a time when yolk absorption was complete, and pike began to actively feed on zooplankton, may support a theory of natural selection to a feeding mechanism through light attraction (in this case the moon), as zooplankton remain in dark bottom waters during the day and vertically migrate to surface waters at night to forage and

avoid predation by visual predators (Stich and Lampert 1981). On the other hand, maybe larval pike typically remain inactive at night, and "artificially" reacted to light traps simply because they could see prey around light sources.

CONCLUSION

This Lake Davis study had little success catching large numbers of pike in light-traps at early larval and juvenile life stages. The limited trapping success did occur at a time that supports a previous study by Girsá (1969). He concluded pike are most responsive to light at 13-17 mm. We found an average size for photo-positive pike to be 13.3 mm.

Each of the light sources tried did attract northern pike. Cyalume lightsticks were more reliable in the field. Battery-powered Krill lamps suffered badly if any water got inside the unit, and batteries needed to be changed often to ensure a full night of illumination.

This field study shows that larval and juvenile northern pike can be light-trapped, however not in high numbers using this methodology. Consistent with Girsá (1969), and Zigler and Dewey (1995), my data supports the theory that there is a window of positive photo-taxis in pike development. Light-trapping of age-0 pike appears to be most productive during this developmental period when pike are at a total length of 13-17 mm.

Though D-netting was not an intended focus of this study, it proved to be the more successful method to trap young-of-the-year northern pike. Further study of this capture method may be warranted.

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